

# Permanent Superhumps in Nova V1974 Cygni 1992

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## ABSTRACT

We present results of 32 nights of CCD photometry of V1974 Cygni, from the years 1994 and 1995. We verify the presence of two distinct periodicities in the light curve:  $0.0812585 \text{ day} \approx 1.95 \text{ hours}$  and  $0.0849767 \text{ d} \approx 2.04 \text{ hr}$ . We establish that the shorter periodicity is the orbital period of the underlying binary system. The longer period oscillates with an average value of  $|\dot{P}| \sim 3 \times 10^{-7}$ —typical to permanent superhumps.

The two periods obey the linear relation between the orbital and superhump periods that holds among members of the SU Ursae Majoris class of dwarf novae. A third periodicity of  $0.083204 \text{ d} \approx 2.00 \text{ hr}$  appeared in 1994 but not in 1995. It may be related to the recently discovered anti-superhump phenomenon. These results suggest a linkage between the classical nova V1974 Cyg and the SU UMa stars, and indicate the existence of an accretion disk and permanent superhumps in the system no later than 30 months after the nova outburst.

From the precessing disk model of the superhump phenomenon we estimate that the mass ratio in the binary system is between 2.2 and 3.6. Combined with previous results this implies a white dwarf mass of  $0.75\text{--}1.07 M_{\odot}$ .

## Key words:

novae - stars: individuals: V1974 Cygni - accretion disks - stars: binaries: eclipsing - stars: oscillations - stars: white dwarf

## 1 INTRODUCTION

### 1.1 V1974 Cygni

V1974 Cygni was discovered on February 19 1992 by Collins (1992). It was the brightest nova since V1500 Cygni, and was soon recognized as a fast one, with  $t_{2V} \approx 16d$ , and  $t_{3V} \approx 40d$ . The prenova was estimated as  $m_V \approx 19.5$ , indicating an outburst amplitude of about 15 magnitude (Annuk, Kolka & Leedjarv 1993). A massive multiwavelengths study of the star has been carried out in the last 5 years, including quite a few optical photometric observations (Hurst 1992, Kidger 1992, Chochol et al. 1993, DeYoung & Schmidt 1993, 1994, Semeniuk et al. 1994, 1995, Retter, Ofek & Leibowitz 1995, Retter, Leibowitz & Ofek 1996).

Periodic oscillations in the light curve (LC) of the star were discovered in 1993 by DeYoung & Schmidt (1993, 1994). They detected a period of  $0.081263 \pm 0.000003 \text{ day}$  in the I band. The modulation was about  $0.16 \pm 0.05 \text{ mag}$ , and its shape was not symmetric, as the rise to maximum was faster than the decline to minimum. The variation was much weaker in the V band ( $0.05 \pm 0.06 \text{ mag}$ ). They interpreted the periodicity as the orbital period, and the modulation as resulting from the varying aspect of the illuminated

hemisphere of the companion by the intense radiation of the hot nova.

Semeniuk et al. (1994) reported the detection of a different periodicity ( $0.0850 \text{ day}$ ) from observations in the V band during 1994. The amplitude of this variation was about  $0.05 \text{ mag}$ , and it had a similar amplitude in the I and the R bands. They also noticed that this period was not stable.

The two distinct periodicities in the LC of V1974 Cyg were also independently discovered by Retter et al (1995). They suggested a connection between the second periodicity of the nova and the superhump (SH) phenomenon in the SU UMa stars.

In a second publication, Semeniuk et al. (1995) confirmed the continued presence of two distinct periodicities in the LC of the nova, the longer of which was decreasing in time. They concluded that the shorter, stable period is the orbital period of the nova system, and attributed the longer one to the spin period of white dwarf (WD) in the system. In their model, the WD possesses a strong magnetic dipole field, the axis of which is inclined with respect to the spin axis of the star. The nova outburst caused the spin of the WD to get out of synchronization with the orbital revolution. The light variation of the longer period results from

a distinct light source (an accretion column) near one of the magnetic poles of the star. The spin period of the WD evolves back into synchronization, hence the change in the longer periodicity.

Retter et al (1996) suggested instead, that the longer photometric period of V1974 Cyg is a disk feature, related to the well known superhump phenomenon in SU UMa stars. In this work we present further evidence in support of our interpretation of the longer period of V1974 Cyg as a SH phenomenon.

## 1.2 The superhump phenomenon in novae and in other CVs

The SH phenomenon is the appearance of a periodic or a quasi-periodic modulation in the LC of the SU UMa class of dwarf novae, during the superoutburst events that characterize the photometric behaviour of these stars. The period of the SH is a few percent longer than the orbital period of the system in which it is observed (laDous 1993). Stolz & Schoembs (1981, 1984) found a linear relation between the relative excess of the SH period over the orbital one, and the orbital period. The commonly accepted interpretation of the phenomenon is that the light modulations result from the precession of the accretion disc around the WD of the underlying binary system. The observed SH periodicity is in fact the beat of the disc precession period in the co-rotating frame and the orbital period of the binary system (Whitehurst 1988, Osaki 1996).

Recently it was suggested that a few classical novae show SH-like characteristics in their optical LCs. For example, Patterson & Richman (1991), Patterson et al. (1993c) and Thomas (1993) suggested a SH interpretation for the double periodicity that was observed in the LC of the classical nova V603 Aquila. A similar interpretation was given to a similar phenomenon in the LC of nova CP Puppis (White & Honeycutt 1992, White, Honeycutt & Horne 1993 and Thomas 1993). Patterson et al. (1993c) suggest also a few other classical novae as potential superhumpers.

The SH phenomenon was also invoked as an interpretation of a few peculiarities in the LC of AM CVn's stars (Patterson, Halpern & Sharnbrook 1993b, Patterson et al. 1993c and Solheim et al. 1996) and in the photometric time series of a few soft x-ray sources (White 1989, Charles et al. 1991, Bailyn 1992, Zhang & Chen 1992 and Kato, Mineshige & Hirata 1995).

Unlike the case in the SU UMa stars, where the SH modulation is a transient feature, in a few of the other CV stars, such as V603 Aql, CP Pup and AM CVn, the systems are believed to experience permanent SHs. The existence of this mode of variation has been theoretically established by Osaki (1996).

## 2 OBSERVATIONS

We observed V1974 Cygni during 32 nights from September 1994 to November 1995. Table 1 presents a summary of the observations schedule. The photometry was carried out with the 1 meter telescope at the Wise Observatory, using the Techtronix 1K CCD camera, described in Kaspi et al. (1995). During the first three nights we switched successively

**Table 1.** The Observations Time Table

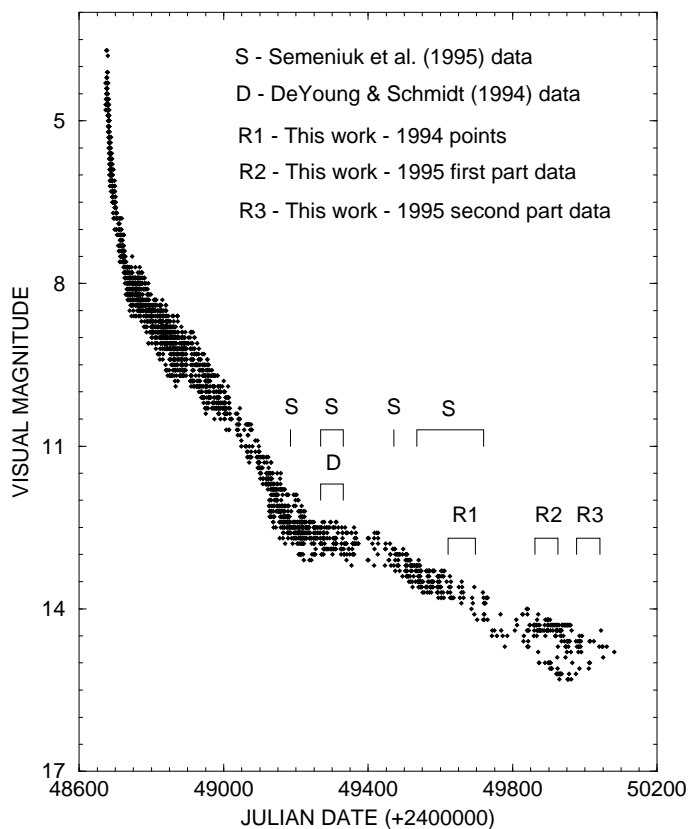
UT Date	Time of Start (JD+2449000)	Run Time (hours)	Points number
240994	620.719	6.5	144
251094	651.699	5	140
011194	658.682	0.25	3
081194	665.656	6	168
061294	693.652	5.5	126
071294	694.649	5.5	124
081294	695.656	5	93
091294	696.669	5	90
101294	697.672	5	90
240595	862.907	4.5	65
250595	863.892	4.5	84
060695	875.967	2.5	41
080695	877.843	5.5	100
090695	878.831	6	109
100695	879.829	6	96
110695	880.823	6	114
250795	924.778	7.5	135
260795	925.780	7.5	140
270795	926.780	7.5	146
150995	976.725	7	160
160995	977.703	7	162
011095	992.697	1	38
021095	993.699	1	26
141095	1005.679	5	93
181095	1009.718	3.75	69
191095	1010.682	3.25	62
201095	1011.685	3.5	38
211095	1012.733	5	88
161195	1038.663	5.5	98
171195	1039.644	1.5	28
181195	1040.655	1	18
191195	1041.662	5	95

between the standard V,R and I filters. In the fourth night the photometry was in the B band, and from then on we used only the I filter. Our I filter is somewhat redder than the standard bandpass, because its red end is determined by our CCD camera cut-off, which has a longer tail into lower frequencies. The typical exposures times were between 1 to 3 minutes. The number of frames obtained in each filter on our programme is: 2620 (I), 100 (R), 96 (V) and 67 (B).

Photometric measurements were performed using the DAOPHOT program (Stetson 1987). Instrumental magnitude of the nova, as well as of 3 to 20 reference stars, depending on the site photometric conditions, were obtained from each frame. An internal consistent series of nova magnitudes was obtained by using the Wise Observatory reduction program DAOSTAT (Netzer et al. 1996).

Fig. 1 displays a comprehensive LC of the nova in the V band from outburst to December 1995. The data was taken from AFOEV database, CDS, France. The lower marks in the figure indicate the times of our observations. They are divided into three sub-groups: September–December, 1994 (R1), May–July, 1995 (R2), and September–November, 1995 (R3). The times of observations by DeYoung & Schmidt (1994), and by Semeniuk et al. (1995) are marked in the figure as well.

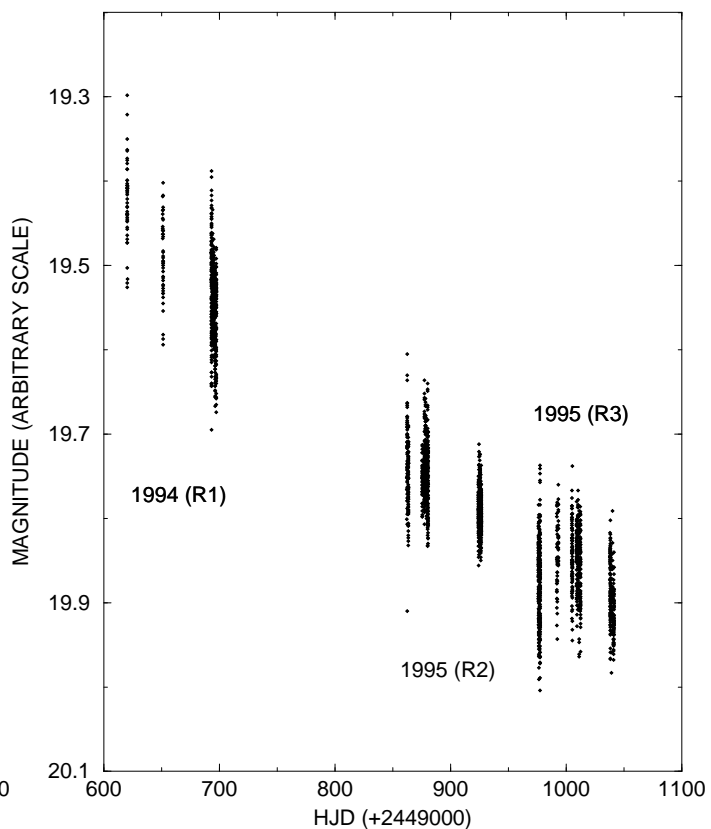
Figure 2 presents the entire I LC of the nova, as measured in our observing programme. One can see that during



**Figure 1.** The light curve of Nova Cyg 92. Data points are visual estimates of amateur astronomers, compiled by AFOEV. The times of observations by DeYoung & Schmidt (1994), and by Semeniuk et al. (1995) are marked, along with the times of our own observations. The latter are divided into three sub-groups: September–December, 1994 (R1), May–July, 1995 (R2), and September–November, 1995 (R3).

the time interval spanned by our observations, the nova declined by about 0.5 magnitude. There is also some variation from night to night in the nightly average magnitude. Some of it may be related to the beat period between the two periods of  $\sim 2$  hours that characterize the LC of the nova (see below).

The LC of the nova in all four passbands exhibits a sinusoidal like modulation. Although our observations in the B,V and R bands are much fewer than in I, we still can appreciate that the peak to peak amplitude of the variation seems to be similar in all bands, varying between 0.05 and 0.10 magnitude from night to night. Thus it appears that the short term optical light variations, of about 2 hours time scale, are independent of colour. Closer examination of the modulation reveals that it is asymmetric, with a rise to maximum that is slower than the decline to minimum. We note that this structure is different from the one observed previously by DeYoung & Schmidt in 1993.



**Figure 2.** All I magnitudes of V1974 Cyg measured in this work, divided into three sub-groups.

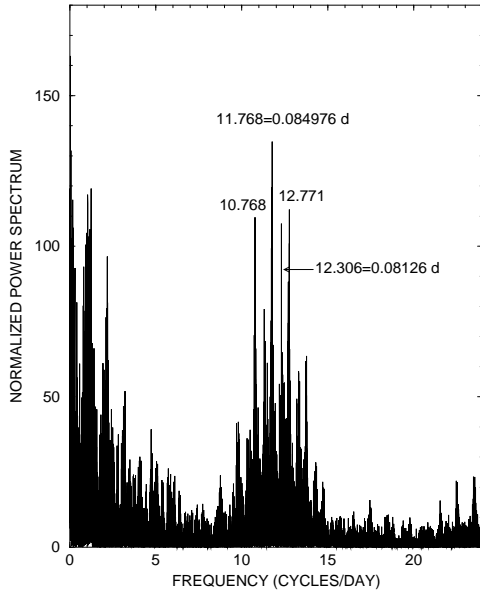
### 3 DATA ANALYSIS

#### 3.1 The two major periodicities

Figure 3 is a plot of the normalized power spectrum (PS) (Scargle 1982) of all our 2620 I band points, after dereddening by subtracting a second degree polynomial from the data. The PS is dominated by two similar patterns of  $1,1/2,1/3$  etc. day aliases around the two central frequencies of  $11.76792 \text{ day}^{-1}$  ( $P=0.0849767 \pm 0.0000005 \text{ day}$ ), and  $12.30640 \text{ day}^{-1}$  ( $P=0.0812585 \pm 0.0000005 \text{ day}$ ). See also Figures 4 and 7 for a magnification of the relevant range.

The group of peaks at the lower end of the PS corresponds to periodicities, that are longer than one night in our observing program. Their presence in the PS is sensitive to the dereddening procedure and therefore their reality cannot be determined from our data.

In order to check the reliability of the two independent periodicities in the LC of the nova, we subtracted from the data the first harmonic of the  $0.0849767 \text{ day}$  period. The PS of the residuals shows clearly the shorter,  $0.0812585 \text{ day}$  periodicity as a dominant peak in the PS. Conversely, when the shorter period is removed from the data, the longer one remains clearly in the residual LC. As a further check we created an artificial LC on the times of the real observations, by superposing a sine wave of one of the two periodicities over a random distribution of points representing



**Figure 3.** Normalized power spectrum of the entire I LC. The two double structures of peaks around the central frequencies 11.768 and 12.306 is the pattern of 1, 1/2, 1/3 etc. day aliases of these periodicities.

white noise. The PS of each of these synthetic LCs showed only the corresponding planted periodicity, surrounded by an alias pattern similar to the one of the real data, with no trace of the other periodicity.

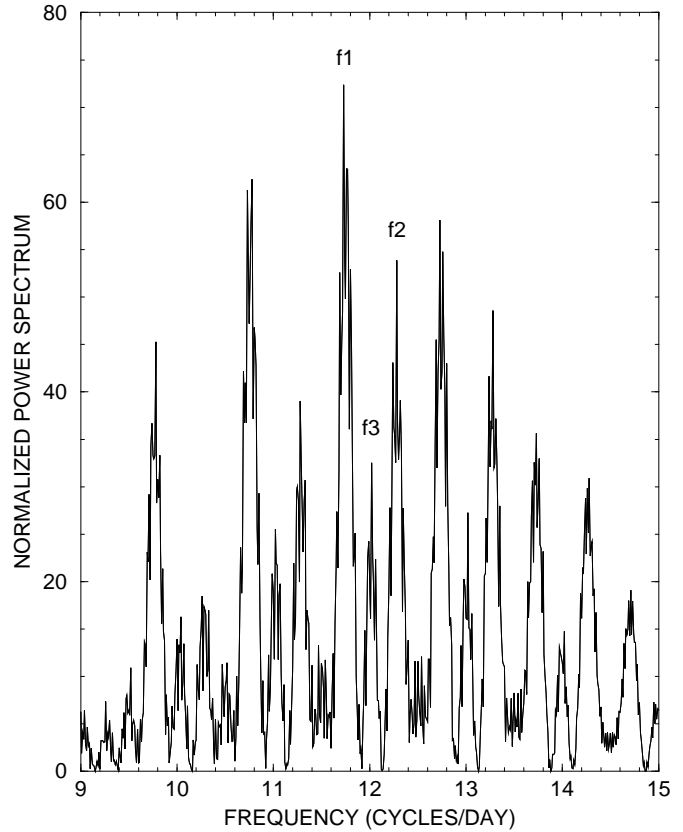
### 3.2 Other periodicities

We further checked the data for possible additional short term periodicities. This was done by computing the PS of the LC of the star, in each of the individual nights of our observations. These power spectra were then added together to form an average nightly PS of the star (see Skillman, Patterson & Thorstensen 1995, Patterson 1995). No periodicity in the range from the Nyquist frequency to the longer period of about 2 hours stands out in this PS.

We also examined the harmonics of the main 11.76792 frequency in a motivation to see whether they are displaced towards the blue, an effect, which is reported in a few SU UMa systems (Patterson et al. 1995a and Harvey & Patterson 1995). The second harmonic is found at 23.61 cycles/day—about 0.3 percent larger than twice the fundamental frequency. The third harmonic is 35.36 cycles/day—0.2 percent positively misplaced. The higher harmonics did not rise above the noise level. Most of the harmonics of the three different parts of the data mentioned above showed similar shifts, but the effect was less obvious.

### 3.3 The 1994 light curve

Fig. 4 displays the normalized PS of the 1994 I data, zoomed on the close neighborhood of the two frequencies discussed in a previous section. The two peaks, corresponding to these frequencies, along with the daily alias pattern around each

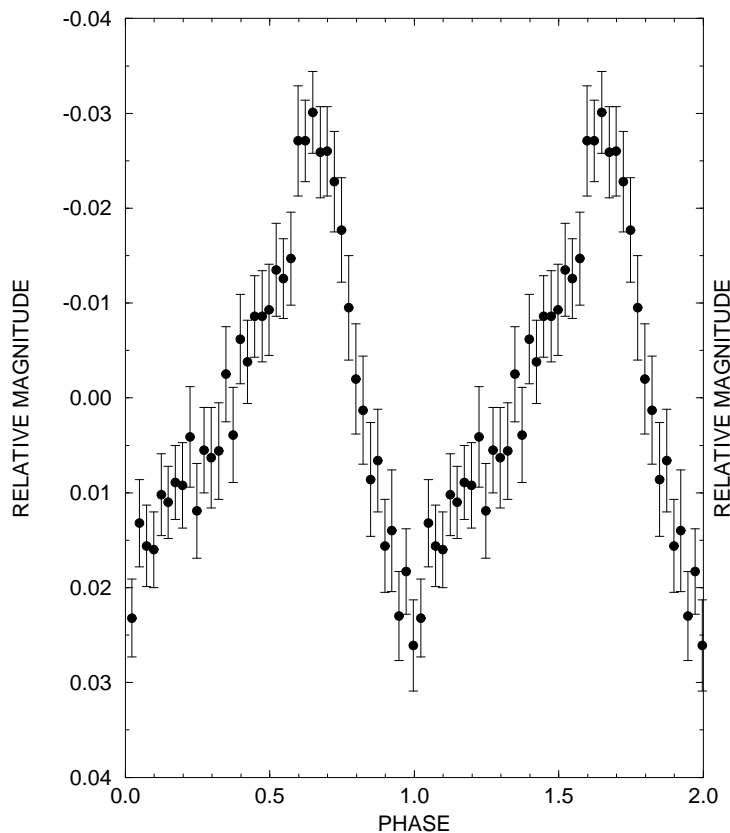


**Figure 4.** Normalized power spectrum calculated from the I band points in 1994. Two similar patterns of peaks around the central frequencies 11.768 (f1) and 12.306 (f2) are clearly seen, as in Fig. 3. A third lower peak around the frequency 12.019 (f3) indicates the presence of another true periodicity in the LC—see text.

one of them, are clearly seen in the figure. However, a third periodicity of  $0.083204 \pm 0.000001$  day, together with its own one day alias pattern, is also present in the PS. This pattern of triple frequencies is absent from the PS of the 1995 data, in which only the two major periods stand out, as in Figure 3. We checked the independence of the third periodicity that appears in 1994, with the same two methods discussed above. We found that during the 1994 observational season, the LC of the nova has indeed been modulated by a third, independent periodicity of 0.083204 day, in addition to the other two major periods. Due to the scarcity of the 1994 data, however, and since the third period did not re-appear in 1995, we must regard this conclusion as uncertain.

### 3.4 Structure of the 2 periodicities

In Fig. 5 we show the I band data, folded onto the 0.0849767 day period. The points are the average magnitude value in each of 40 equal bins that cover the 0-1 phase interval. The bars are the  $1\sigma$  uncertainties in the value of the average values. The peak to peak amplitude of the average variation is about  $0.055 \pm 0.010$  magnitude. The periodic photometric cycle is clearly asymmetric, with a slow, stepwise rise to



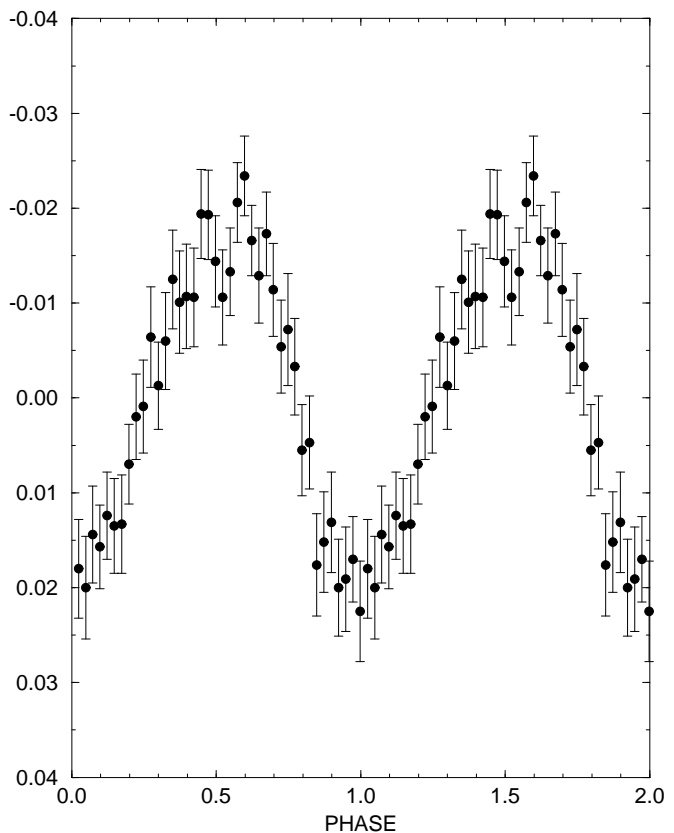
**Figure 5.** The I filter light, folded onto the 0.0849767 day period, and binned into 40 equal bins.

maximum and a fast decline to minimum. Similar values for the variation amplitude are deduced from the different three parts of our data discussed above.

Fig. 6 displays the LC, folded onto the shorter 0.0812585 day period, with the same binning and symbols as in Figure 5. This LC is rather sinusoidal in shape, with a peak to peak amplitude of about  $0.042 \pm 0.010$  magnitude. Again, within the error limits, the amplitude of the variation during the three parts of the observations is the same.

A noteworthy feature seen in Fig. 6 is the brief shallow dip in the light curve at phase 0.5. Its reliability was checked by subtracting a pure sinusoidal from the folded and binned data, resulted in a distribution of the points around the zero level, with three adjacent points lower than the others at the relevant phase. These three points were at  $1.2$ ,  $2.4$  and  $1.5\sigma$  from the expected value. The chances to find such points together around a unique area at the LC (phase 0.5) are less than 0.01 percent. All folded LCs of the three parts of the data (September–December, 1994, May–July, 1995, and September–November, 1995) show similar behaviour at this phase.

Our data is consistent with the notion that there is no long-term variation in the amplitude of the two periodicities, derived from the three epochs of our observations. However, comparing these results with the values, determined by DeYoung & Schmidt (1994) and by Semeniuk et al. (1995), it is



**Figure 6.** The light curve, folded onto the shorter 0.0812585 day period. Binning is as in Fig. 5. Note the eclipse-like shape at phase 0.5—half a cycle after minimum of light.

clear that the amplitude of the photometric binary variation decreased sharply from 1993 to 1994.

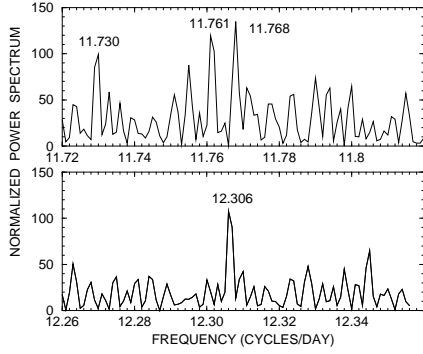
### 3.5 Coherence of the two periodicities

Fig. 7 is a zoom picture of two sections of the PS of V1974 Cyg seen in Figures 3 & 4, in the immediate neighborhood of the two major frequencies of the system. It is quite noticeable that the higher frequency is represented by a distinct, single peak, while the lower frequency, although appearing with more power in the spectrum, is represented by a group of peaks rather than by one. The light variation corresponding to this frequency should therefore be rather regarded as a quasi-periodicity.

In view of this difference we hereby give the best fitted ephemeris of the shorter periodicity:

$$T_{min} = \text{HJD } 2449693.2117 + 0.0812585 \text{ E.} \\ \pm 0.0005 \quad \pm 0.0000005$$

In order to characterize further the nature of the quasi-periodicity around the lower frequency  $11.76792 \text{ day}^{-1}$ , we plot in Figure 8 the O-C values of times of maximum in the LC of the nova. We derived times of maxima from our own observations by considering a third order polynomial that



**Figure 7.** The immediate vicinity of the two frequencies in the power spectrum of V1974 Cyg. The shorter 11.76792 frequency seen at the upper panel, has several neighboring peaks with similar power in each. The higher 12.30640 frequency at the lower panel is a single isolated peak in the graph.

was fitted by least squares to the observed points around phases of maximum. A third degree was adopted because of the asymmetrical shape of the variation in the cycle (see Figure 5). Following Semeniuk et al. (1995), we took into account maxima from all filters. The maxima are listed in Table 2. The  $1\sigma$  errors are of the order of 0.005 day.

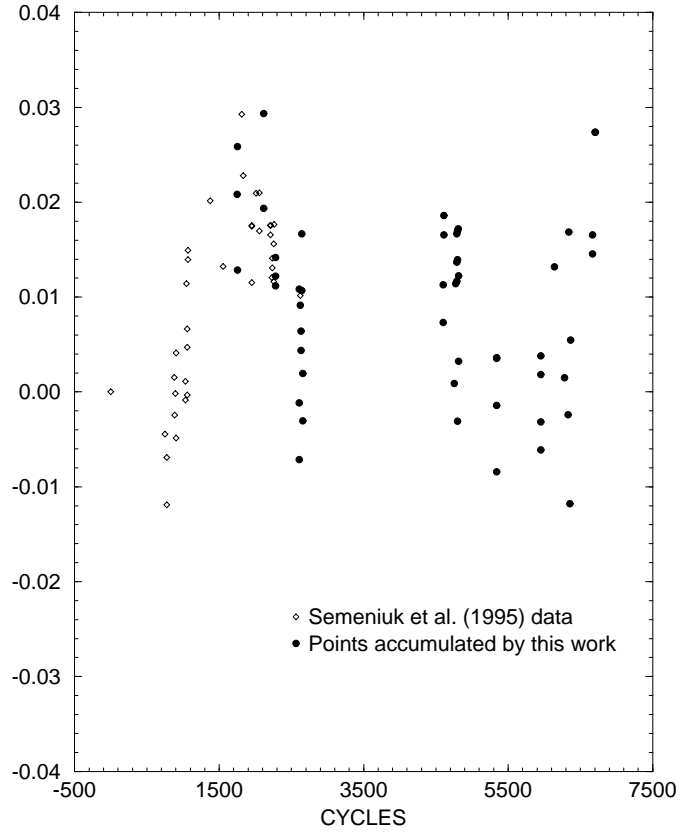
We get similar results when we fit to the data three harmonics of the two periods simultaneously, and after subtracting the harmonics of the shorter period from the data. In this way the effect of the shorter periodicity is nearly eliminated. The maxima in the LC of the residuals are less distinguishable than the maxima identified directly in the raw data, but the O-C graph remains essentially unaltered.

The plot in Fig. 8 includes in addition to our own maxima values also times of maxima determined by Semeniuk et al. (1995). Neglecting the first point, we can see at least two changes in the periodicity—a decrease of the period at the left hand side of the diagram in 1994, and an increase at the right hand side during 1995. Additional changes in the sign of  $\dot{P}$  may have occurred at the gap in the observations, during the beginning of 1995.

It should be mentioned that the O-C diagram of the minima shows very similar features. We also checked the increase of the period during 1995, by dividing the data of that year into two sub-groups (May–July, 1995, and September–November, 1995). We then fitted simultaneously three harmonics of the two periodicities to the data, and subtracted the terms of the higher, assumed fixed, 12.30640 frequency. The PS of the residuals of the first, earlier group yielded a period of 0.084955 day, while the peak of the PS of the late group was at about 0.085005 day. This check confirms the increase of the period during 1995, and fits exactly the periods values, derived from the O-C diagram, assuming constant  $\dot{P}$  during the two epochs.

Fig. 8 demonstrates that the longer period oscillates around a certain value, so its mean derivative over a long time should be zero. However, in order to give a general estimation of  $\dot{P}$ , we considered just the 1995 data, in which the period increased. The result is:

$$\dot{P} \sim (0.085005 - 0.084955)/180 \sim 3 \times 10^{-7}.$$



**Figure 8.** O-C diagram of the 0.0849767 day period. Two obvious changes in  $\dot{P}$  are seen: a decrease of the period around cycle 2000 and an increase at about cycle 6000.

Similar absolute value with the opposite sign describes the period change in 1994.

## 4 DISCUSSION

### 4.1 The two periodicities in the LC of the nova

The large amount of continuous photometric data on V1974 Cygni, accumulated by DeYoung & Schmidt (1994), Semeniuk et al. (1994, 1995), and in this work confirms undoubtedly the presence of two independent periods—0.0812585 day and 0.0849767 day in the LC of this nova. The persistence of the shorter period in the LC during more than two years, its presentation in the PS as an isolated narrow peak, and the structure of its average cycle, with the apparent dip at phase 0.5, suggest strongly that it is the orbital period of the binary system.

While there is a general agreement that the shorter period is indeed the binary period of the system, the nature of the second periodicity is controversial. Two different explanations for it have been suggested so far. The first one invokes the existence of a strong magnetic field on the surface of the WD (Semeniuk et al. 1994, 1995), and the second offers the presence of an accretion disk around the primary star (Retter et al. 1995, 1996).

**Table 2.** Maxima times of the 0.0849767 day period

HJD	Filter	Cycle	O - C (days)
2449620.27	I	1750	0.021
2449620.347	V,R,I	1751	0.013
2449620.445	V,I	1752	0.026
2449651.295	V,I	2115	0.029
2449651.37	I	2116	0.019
2449665.216	B	2279	0.014
2449665.298	B	2280	0.011
2449665.384	B	2281	0.012
2449693.17	I	2608	0.011
2449693.243	I	2609	-0.001
2449693.322	I	2610	0.007
2449694.273	I	2621	0.009
2449695.203	I	2632	0.010
2449695.290	I	2633	0.006
2449696.235	I	2644	0.017
2449696.314	I	2645	0.011
2449697.24	I	2656	0.002
2449697.32	I	2657	-0.003
2449862.444	I	4600	0.007
2449862.525	I	4601	0.007
2449863.469	I	4612	0.017
2449863.556	I	4613	0.019
2449875.52	I	4754	0.001
2449877.40	I	4776	0.011
2449878.34	I	4787	0.017
2449878.420	I	4788	0.012
2449878.507	I	4789	0.014
2449879.34	I	4799	0.003
2449879.442	I	4800	0.014
2449879.53	I	4801	0.017
2449880.380	I	4811	0.017
2449880.451	I	4812	0.003
2449880.545	I	4813	0.012
2449925.319	I	5340	0.004
2449925.392	I	5341	-0.008
2449925.484	I	5342	-0.001
2449925.574	I	5343	0.004
2449977.240	I	5951	0.004
2449977.318	I	5952	-0.003
2449977.408	I	5953	0.002
2449977.485	I	5954	0.006
2449993.225	I	6139	0.013
2450005.28	I	6281	0.002
2450009.27	I	6328	-0.002
2450010.224	I	6339	0.017
2450011.47	I	6354	-0.012
2450012.422	I	6365	0.006
2450038.264	I	6669	0.015
2450038.351	I	6670	0.017
2450041.251	I	6704	0.027
2450041.336	I	6705	0.027

## 4.2 Superhump interpretation

The variation on the 0.085 day is quasi-periodic, as we have seen in Fig. 8, and about 4.6 percent longer than the assumed orbital period. The periods range and the difference between them are similar to those found in SU UMa stars. Table 3 presents the observed periods in this group, as well as the corresponding SH relative period excesses (the differ-

**Table 3.** SU Ursae Majoris Periods

Object	$P_1$ -orbital (min)	$P_2$ -superhump (min)	$(P_2 - P_1)/P_1$
AL Com	81.60	82.58	0.0120
WZ Sge	81.63	82.28	0.0080
SW UMa	81.81	83.99	0.0266
HV Vir	83.51	84.46	0.0155
WX Cet	83.94	85.48	0.0183
T Leo	84.70	86.70	0.0236
AQ Eri	87.75	90.25	0.0285
V1159 Ori	89.83	92.40	0.0286
V436 Cen	90.00	91.91	0.0212
OY Car	90.89	93.07	0.0240
VY Aqr	91.41	92.70	0.0141
ER UMa	91.67	94.46	0.0304
SS UMi	97.60	101.00	0.0348
TY Psc	98.40	101.00	0.0264
IR Gem	98.45	102.00	0.0361
CY UMa	100.18	104.26	0.0407
FO And	103.12	105.00	0.0182
HT Cas	106.05	109.55	0.0330
VW Hyi	106.95	110.49	0.0331
Z Cha	107.28	111.18	0.0364
WX Hyi	107.73	111.46	0.0346
SU UMa	109.94	113.50	0.0324
V503 Cyg	111.90	116.70	0.0429
TY PsA	121.16	126.22	0.0418
YZ Cnc	125.00	131.90	0.0552
TU Men	169.34	180.83	0.0679

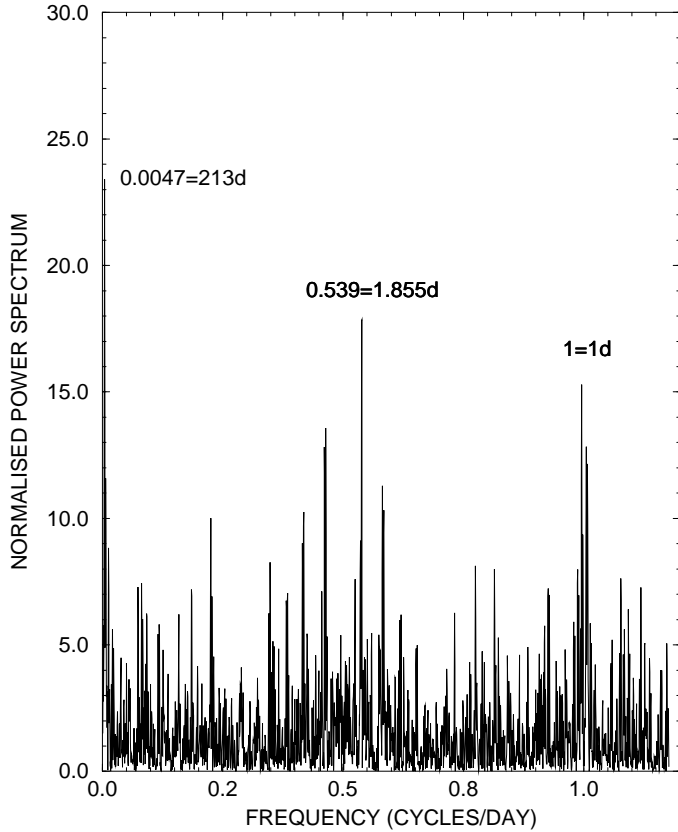
ence between the SH and the binary periods, divided by the binary period), taken from Thorstensen et al. (1996).

The well known relation between the two periods of SU Ursae Majoris stars (Stolz & Schoembs 1981, 1984) is shown in Fig. 9, where the point, representing the two periods of V1974 Cygni (cross), is also marked. It is clear that the nova fits well within this relation.

This fact suggests a possible linkage between the two periods of the classical nova V1974 Cygni and the SH phenomenon in SU UMa stars. Further indication of the link comes from the quasi-periodic nature of the longer periodicity, which is a common characteristic of SHs periods (e.g. Patterson et al. 1993a, Leibowitz et al. 1994). This similarity to the SH phenomenon is quantitative as well. In Section 3.5 we estimated the average rate of period change in the LC of the nova as  $|\dot{P}| \sim 3 \times 10^{-7}$ . This value is in the range of the values of this parameter as found in permanent SHs:  $10^{-8} - 5 \times 10^{-6}$  (Patterson & Skillman 1994).

We note here that the amplitude of the longer period ( $\sim 0.055$  mag) is much lower than superhumps amplitudes in regular SU UMa systems (about 30–40 percent—laDous 1993). It is, however, similar to the typical amplitude of the variation in permanent superhumps (e.g. Patterson et al. 1993c, Patterson & Skillman 1994).

Another two observational features of the LC of V1974 Cyg are also very much in line with the SH interpretation. The first one is the third periodicity that is found to be present in the 1994 LC (Section 3.3). A third period, nearly equal to the binary one but somewhat shorter, has been found in a few superhumpers (Patterson et al. 1993c, Harvey et al. 1995, Patterson 1995 and Patterson et al. 1995a). We



**Figure 9.** Superhump relative period excess vs. orbital periods in the group of all SU UMa stars for which these values are known. The two periods of V1974 Cyg, represented by the cross, obey well this relation.

do not make an attempt in this work to interpret the 1994 third periodicity of Nova Cyg 92, but the phenomenological similarity of it with the “anti-superhump” effect in superhumpers may be considered as a further supporting evidence for the SH interpretation of the V1974 Cyg LC. The third period found in V1974 Cyg isn’t shorter than the orbital period of the nova as expected from anti-superhumps, nevertheless it can be interpreted as a real anti-superhump if we consider instead its 1 day alias—0.0768 day, which has almost the same strength in the PS. The interesting phenomenon of a third periodicity should be checked in V1974 Cyg and other superhumpers in the future.

The second support comes from the apparent displacement towards the blue of the high harmonics of the longer periodicity of V1974 Cyg. Again, we do not give here an interpretation of this effect. We do draw attention to the fact that a similar phenomenon has been observed in PSa of established SU UMa systems (Patterson et al. 1995a and Harvey & Patterson 1995).

### 4.3 Magnetic interpretation

A different interpretation of the second, longer periodicity in the LC of V1974 Cyg has been suggested by Semeniuk

et al. (1994, 1995). These authors suggest that V1974 Cyg is akin to polar (or intermediate polar) systems. In particular they propose that the longer period of N. Cyg 92 is the spin period of the WD in the system. It is manifested as light variation because an intense dipole magnetic field on the surface of the WD funnels accreted matter onto an accretion column around one of the magnetic poles of the star. The WD magnetic dipole is not aligned with the spin axis of the star, and therefore the magnetic poles are spinning with the star rotation. The pole onto which matter is being accreted is a hot area in the system that changes its aspect with the WD spin. Semeniuk et al. speculate that the nova eruption caused the WD rotation to get slightly out of synchronization with the orbital frequency, hence the difference between the two periodicities. According to this model, the tidal effects that synchronize close binary systems are operating now to re-synchronize the WD spin to the orbital cycle. The expected observational result should be a permanent trend of the longer period to approach the shorter value.

### 4.4 Evaluation of the two interpretations

In Section 3.5 we showed that no uniform trend is observed in the difference between the two periods of V1974 Cyg along the two years LC of the star. Instead, the value of the longer period seems to oscillates around a mean value. In particular, in summer 1995 it went against the trend expected in the nearly synchronous interpretation, it has *lengthened* rather than becoming shorter.

Observationally, similar trend towards synchronization of the second period has indeed been detected. In the well studied nova, V1500 Cyg (N. Cyg 1975) and in BY Cam = H0538+608, in which the WD is believed to rotate out of synchronization, the shorter of the two periods in the LC are indeed becoming longer, evolving towards synchronization with the orbital, longer periodicity (Pavlenko & Pelt 1991, Schmidt & Stockman 1991, Silber et al. 1992, Schmidt, Liebert & Stockman 1995 and Pirola et al. 1994).

Further arguments against the a-synchronous interpretation of the second period can be raised on the basis of a comparison of other features of the two periods phenomenon in V1974 Cyg with the cases where the nearly synchronous rotation is commonly believed to be observed. So far there are 3 such cases: V1500 Cygni and BY Cam, mentioned before, and RX J19402-1025 (Patterson et al. 1995b). The binary periods of all 3 systems are around 3.36 hours (Patterson et al. 1995b), whereas that of V1974 Cyg is merely  $\sim 2$  hours. This difference may well be a coincidence, but it is worth being pointed out.

Another significant difference between V1974 Cyg and a-synchronous rotating polars is that with one exception (RX J19402-1025), all polars have spin periods shorter than the orbital period (e.g. Patterson 1994). In V1974 Cyg, on the other hand, the non-orbital period is longer than the orbital one. RX J19402-1025 with a negligible period excess  $(P_{\text{spin}} - P_{\text{orbital}})/P_{\text{orbital}} \sim 0.3\%$  is not well understood since the accreted matter onto the primary should spin up the rotation of the WD.

Additionally, the period excess is quantitatively much larger in Nova Cygni 1992 (about 4.6%) than in the three a-synchronous cases: about -1.8% in V1500 Cyg (see for ex-



ample Semeniuk et al. 1977, Stockman, Schmidt & Lamb 1988, Pavlenko 1992), -1.3% for BY Cam (Silber et al. 1992) and 0.3% in RX J19402-1025 (Patterson et al. 1995b).

An attempt to explain this difference by the time elapsed since the nova eruption, assuming all three asynchronous systems are old novae, is refuted by the case of V1500 Cyg. In this nova, the small value has been already measured one year after maximum light.

Therefore, it seems to us that the observed data in V1974 Cyg are better interpreted in terms of disk dynamics, akin to the permanent SH phenomenon, rather than reflecting a rotating magnetic field on the surface of the WD in the system. We wish to emphasize, however, that our interpretation does not exclude the possibility that an intermediate polar model may well be fitted to this nova system.

#### 4.5 The precessing disk model—deriving the binary masses

Mineshige, Hirose & Osaki (1992) applied observational considerations to a theoretical equation of Osaki (1985). They present an equation, relating the SH periodicity to the parameters of the underlying binary system:

$$\Delta P = \frac{q}{4\sqrt{1+q}} \eta^{3/2} \quad (1)$$

where:  $\Delta P = (P_{\text{superhump}} - P_{\text{orbital}})/P_{\text{orbital}}$ ,  $q = M_c/M_{wd}$  and  $\eta = r_d/r_{d,\text{crit}} \approx r_d/0.48a = 0.6 - 1$ .

It allows to put constraints on the mass ratios of SU UMa stars from the observed period excess. Simple approximations lead to the linear relation:

$$q \sim (4 - 9) \Delta P \quad (2)$$

which describes well Fig. 1 of Molnar & Kobulnicky (1992).

Applying equation (2) to Nova Cyg 1992, with  $\Delta P \approx 0.0458$ , we obtain  $q = 0.18 - 0.39$ . The values from the original equation (1) are  $q = 0.20 - 0.39$ . Assuming that the red dwarf fills its Roche lobe, we obtain  $M_c \approx 0.11P(\text{hr}) \approx 0.21 M_\odot$ . We can now give a final estimation for the WD mass:  $0.55 - 1.07 M_\odot$ .

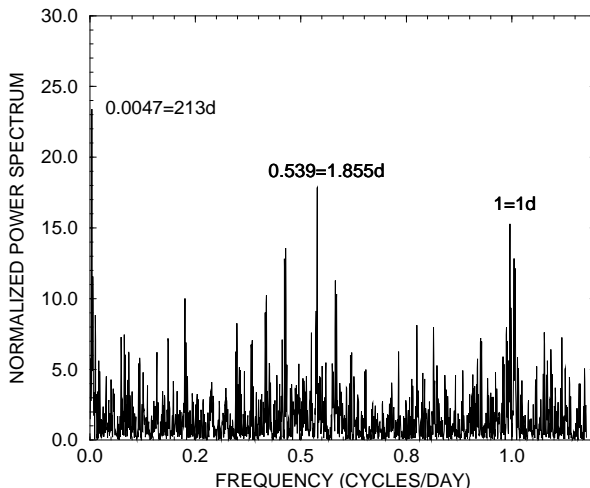
Paresce et al. (1995) used a combination of 5 theoretical and observational considerations to determine the WD mass at the range  $0.75 - 1.1 M_\odot$ . The intersection between this result and ours constraints the WD mass to  $0.75 - 1.07 M_\odot$  and  $q = 0.20 - 0.28$ .

These numbers are inconsistent with the estimation of Austin et al. (1996), who concluded that the mass of the WD is about  $1.3 M_\odot$  from the ejected mass and x-ray considerations.

#### 4.6 The superhump period change

The O-C diagram presented in Figure 8 and discussed in Section 3.5 indicates at least two changes in the  $\dot{P}$  value of the longer periodicity of V1974 Cyg. The lack of observations during the beginning of 1995 prevents the determination of the behaviour of the period during this epoch. However, it seems that the period oscillates around a mean value.

Two different cases can be discussed. If the period was fixed at about 0.084955 day during that time, we might have missed about one cycle, since  $dP/P$  is about  $6 \times 10^{-4}$ , and



**Figure 10.** The power spectrum of O-C points of the longer period. At the left side of the graph there is the probable periodicity of about 213 days which reflects the long term changes in the 0.0849767 day period. The beat period between the two short-term periods (1.855 day) is also seen at the center.

the nova was not observed for about 2000 cycles. In this case the changes in this period may be periodic with a period of about 7500 cycles or 21 months.

Alternatively, during the observational gap the period may have changed its sign twice, increasing first, and then decreasing again. Some support for this notion comes from the first lonely point in the O-C diagram, which suggests another change in  $\dot{P}$ . However, this point may be also one cycle misplaced. The PS of all O-C points is presented in Fig. 10. Its peak is found at 213 day or about 2500 cycles. This is the result of the later hypothesis for the period changes.

If one of these two scenarios is true,  $\dot{P}$  of the quasi-period may be periodic, and we expect the 0.0849767 day period to decrease around July, 1996. We emphasize that, this prediction is valid for the two cases. The two possibilities will become distinguishable towards the end of 1996, when an increase of the period will indicate, that the second possibility is right, while a constant period will be consistent with a longer periodicity of  $\dot{P}$  as the first case.

This prediction should be taken with caution, because we interpret the 0.0849767 day period as a SH period. Changes in SHs are very common in SU UMa stars, and in permanent superhumpers. However, in the few well observed cases known so far, these changes seem to be in the nature of a drift in the period rather than being truly periodic. (See for example the O-C diagrams of AM CVn in Patterson et al. 1993c).

Another interesting feature of the PS of the O-C diagram is the strong peak around the periodicity of 1.855 day, which corresponds to the beat period between the two periods of the nova, the binary and the longer one. This fact is an additional confirmation for the presence of the two independent frequencies, and it can explain the scatter of the points in Fig. 8.

#### 4.7 The overall picture and the orbital dip

The development of the optical photometric features of V1974 Cyg can be simply explained by a model of two distinct major light sources in the system. During the observations in 1993 the variation in the light of the nova was due to reflection from the secondary star in the system, illuminated by the intense radiation from the WD vicinity (DeYoung & Schmidt 1994). As the radiation intensity of the primary weakened, with the decay of the erupting nova, another periodicity became dominant in the LC of the system in 1994.

There is also a significant change in the structure of the binary cycle itself. To the rather smooth, roughly sinusoidal variation in 1993, a shallow eclipse like feature has been added in 1994 and 1995 to the binary LC, half a cycle after minimum light.

According to our suggestion that the second periodicity is a superhump-like phenomenon, the light source that appeared in 1994, is a precessing accretion disk. This would mean that the classical nova V1974 Cyg entered a state of permanent SH (Osaki 1996) a few months after its eruption.

How can the structure of the photometric binary cycle be understood within this framework? We think that the orbital dip at phase 0.5 may give us a clue. Such orbital dips are common in soft x-ray sources, where they appear sometimes not only in an average over many cycles, but even at individual light curves (Callanan, Grindlay & Cool 1995, Kato et al. 1995, Bailyn 1992). Callanan et al. interpreted the modulation in 4U 1916-05 as the obscuration of the accretion disk by the bright spot. This interpretation may also be valid for the variation in the LC of V1974 Cyg.

### 5 SUMMARY AND CONCLUSIONS

The similarity between Nova Cygni 1992 and systems showing permanent superhumps is expressed by the following facts:

1. The presence of two independent periodicities in the light curve, which lie in the short-term range of SU UMa periods.
2. The difference between the two periods is a characteristic of SU UMa systems, in which the longer period is related to the superhump variation. The two periods obey the relation of Stolz & Schoembs (1981, 1984) for the two periods of SU UMa systems
3. The amplitude in the longer period is similar to the values found in permanent superhumps.
4. The assumed superhump variation is in fact quasi-periodic with  $|\dot{P}|$  typical to permanent superhumps.
5. The probable existence of a third periodicity in the power spectrum of the observations in 1994, which may be interpreted as an anti-superhump period.
6. The higher harmonics of the longer period are slightly misplaced towards the blue. Similar shift is found in superhumpers.

The explanation of the longer period as caused by the rotation of the magnetic white dwarf is inconsistent with the fact that the system does not march towards synchronization. Essentially only one polar system with  $P_{spin} > P_{orbital}$  is known (RX J19402-1025), but with negligible period excess (0.3%).

The features described above may fit the intermediate polar model, if another short periodicity—the spin period may be found in the future.

Our results suggest, therefore, the presence of an accretion disk in the V1974 Cyg stellar system no later than 30 months after the outburst of the nova. The system is in a state of superoutburst (permanent superhump) for more than two years, up to the present time.

The precessing disk model and previous results constrain the binary parameters to the domains:

$$0.75 \leq M_{wd}/M_{\odot} \leq 1.07 \text{ and } 0.20 \leq q \leq 0.28.$$

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